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Semiannual Technical Summary

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ARPA Authoring System

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Prepared for the Defense Advanced Research Projects Agency under Electronic Systems Division Contract F19628-78-C-0002 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

ARPA AUTHORING SYSTEM

SEMIANNUAL TECHNICAL SUMMARY REPORT
TO THE
DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

1 APRIL – 30 SEPTEMBER 1978

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LEXINGTON MASSACHUSETTS

ABSTRACT

A review is presented of the project to develop and field test the ARPA Authoring System for use by subject-matter experts in the preparation of task training in on-the-job environments. Materials were prepared according to the ARPA Authoring System procedures, and both preparation and delivery were on the facilities of the Lincoln Terminal System. An analysis of the lesson production rates for 30 lessons prepared by Air Force personnel revealed no systematic effects related to individual author, authoring experience, or lesson type. Preliminary results from a field test of the materials indicate that the lessons are sound. Large savings were found in the time trainees require to reach job qualification and in the amount of labor that subject-matter experts must dedicate to training duties.

CONTENTS

ARPA AUTHORING SYSTEM

I. INTRODUCTION

This is the final Semiannual Technical Summary report of this development project. The primary goal was to develop a system for subject-matter experts to author materials in the on-the-job environment. The area of application selected was task training, the kind of instruction provided at the work site in one-on-one tutorial mode to bridge the gap between formal technical schooling and actual readiness to perform work. The immediate goal was to demonstrate that expert technicians could prepare training materials for delivery on a computer-based delivery system. The intent is to capture training in lessons when the expert technicians are available, so that training can be conducted at times when the experts are preoccupied. The project included development of the authoring system, recording and analysis of lesson production costs, test of the lessons produced, and assessment of the impact of this form of instruction on performance training in on-the-job environments.

The project was a joint venture. The Air Force Communications Services (AFCS) Command provided subject-matter experts as authors and a work setting within which to test the lesson products. Lincoln Laboratory constructed the hardware elements to support the tests: a Lincoln Terminal System (LTS)[1] consisting of five LTS-5 instructional delivery units and one ALR (Audio/Logic Recorder) – a small computerized facility on which to make audio recordings, to program lessons, and to analyze student records. Facilities were also provided for conversion of visual materials and tape recordings to microfiche (film cards) suitable for the LTS-5.

The LTS that combines micrographic and microprocessor technology was developed especially as a technology-based system for on-the-job training. There are two principal features of the LTS that distinguish it from other computer-based means of instruction: (a) The LTS-5 operates stand-alone, connected only to a source of electric power; and (b) the System depends on conventional techniques for the design of lesson materials. The delivery of instruction is substantially automated, and the preparation of materials can be done by the usual training personnel. The effectiveness of LTS training has been demonstrated previously on subjects such as basic electronics for Air Force technicians,[2-4] electrical practice for coal miners,[5] and digital-systems engineering for graduate engineers.[6]

The project has provided an opportunity to study the means for generating computer-based instruction under unusual circumstances:

- Subject-matter experts as authors (not educational specialists)
- A procedural approach to managing the authoring process (as contrasted to training the authors in educational techniques)
- Computer-based instruction at scattered locations in the on-the-job environment (not in a school setting)
- Technology-based work performance training (not labor intensive tutoring).

In addition, the Air Force has been able to test a new solution to a persistent training problem – the acute shortage of experienced technicians to conduct training at the work site. It has permitted Lincoln Laboratory to complete implementation of the LTS by providing authoring procedures in a critical applications area. Finally, the project has served as a test bed for the new, prototype hardware for the Lincoln Terminal System developed by the U.S. Bureau of Mines.

II. THE PROJECT

A. Activities

The project[7-10] was carried out in three phases:

> Phase 1: March 1976 – October 1976. The first version of the authoring procedures was prepared. Two LTS-5 units were constructed for tests of lessons.
>
> Phase 2: October 1976 – August 1977. The authoring procedures were used by technical sergeants, and the lessons produced were tested on novice technicians on a limited scale; the authoring procedures[11,12] were revised on the basis of results. Management procedures[9,11] for use at the unit level to direct the lesson-development efforts were prepared. Plans were developed for a full-scale operational test and evaluation of the authoring and instructional delivery systems in FY 78.
>
> Phase 3: September 1977 – September 1978. Thirty lessons on the AN/TRC-97A radio set were prepared by Air Force technical personnel as finished materials. The lessons were converted to microfiche by Lincoln personnel. Data on the authoring effort were gathered for all lessons and analyzed. Assistance was given to the Command to establish an evaluation of the cost and effectiveness of the training by an independent research organization. Preliminary results of the training were analyzed, and the implications of the findings are reviewed below.

B. Participants

The major participants were Lincoln Laboratory – who provided technical services, procedures, and facilities to support authoring and training – and the Tactical Communications Area Command within the AFCS who provided the field environment and resources necessary to test the new technology. Lincoln participation was funded largely within the ARPA Authoring System budget, and the AFCS contribution was in the form of personnel and facilities. Additional funds were obtained from the PRAM office of the Air Force Logistics Command. PRAM is a special program to assist Operational Commands in the field testing of new technology for which near-term cost benefits are apparent. The PRAM money provided for more instructional units and for the independent evaluation of the effort, upgrading the field trial to one representative of a full-scale initial operational test and evaluation. The Human Resources Laboratory of the Air Force Systems Command assisted in establishing the evaluation study.

III. AUTHORING SYSTEM EVALUATION

A. Lesson Preparation

The area of application chosen for the test of the authoring procedures was training on performance of maintenance procedures on the AN/TRC-97A radio set, a large transmitter/receiver located in a mobile communications van. Thirty lessons were prepared by airmen and technical sergeants on the topics listed in Table I. The lead center for the authoring effort was the 5th CCGp (Combat Communications Group) within Tactical Communications Area of the AFCS, at Robins Air Force Base, Georgia.

The principal independent variables identified as of interest relative to the authoring process were:

- Author: principal person implementing a lesson
- Preparation Sequence: first-vs-second effort by an author
- Lesson Type: task-with-explanation vs pure procedure.

TABLE I

LESSONS PREPARED FOR THE AN/TRC-97A RADIO SET

Category	Title
1. Performance Checks	1. Shelter and Equipment Turn-On 2. Normal and Emergency Turn-Off 3. Power Amplifier Turn-On 4. Power Amplifier Turn-Off 5. Multiplexer Loop Performance Check 6. Synthesizer Frequency and Power Check 7. Exciter Performance Check 8. RF Loop Performance Check 9. Receiver (FM) Quieting Performance Check
2. Adjustments and Alignments	1. Multiplexer Voltage Regulator and Master Oscillator Alignment 2. A7 Test Set Operation and Alignment 3. Multiplexer Transmit Path Alignment 4. Multiplexer Receive Path Alignment 5. Multiplexer Alarm Alignment 6. Multiplexer Ring Window Alignment 7. Modulator Alignment 8. Threshold Extender Adjustment 9. Signal Comparator Alignment 10. Radio Net Gain Adjustment 11. RF Power Monitor Meter Calibration 12. Power Amplifier Low Power Alarm and A24 Monitor Alignment 13. Teletype Adjustment 14. A21 Power Supply Alignment
3. Miscellaneous	None
4. Operations	1. Operation of the Pocket Transit 2. Remote Alarm Monitor (BZ-109) 3. Jamming and ECM 4. Operation of the Control Monitor 5. Operation of Test Equipment 6. Site Installation 7. Van Orientation

TABLE II

CONDITIONS OF AUTHORING AND MEASURES OF PERFORMANCE IN THE PRODUCTION OF 30 LESSONS FOR THE AN/TRC-97A RADIO SET

Conditions					Measures						
						Man-Hours of Effort					
Lesson*	Author	Effort	Station Type†		Days	Author	Support	Total	Frames	Time-per-Frame
2.9	A	1	2nd	83%	113	460	20	480	62	7.7
2.4		2		75	47	240	16	256	36	7.1
4.7		3		3	45	282	8	290	70	4.1
1.1	B	1	5th	54	41	144	234	378	37	10.2
1.3		2		78	73	325	114	439	40	11.0
1.2	C	1	5th	48	112	240	150	390	26	15.0
4.4		2		52	69	220	40	260	23	11.3
4.6		3		68	50	90	15	105	24	4.4
4.1	D	1	2nd	54	123	395	55	450	38	11.8
2.3		2		56	115	209	1	210	52	4.0
2.8		3		50	10	48	0	48	12	4.0
4.5		4		100	10	86	0	86	17	5.1
2.1	E	1	2nd	42	144	350	150	500	30	16.7
2.2		2		98	79	438	26	464	53	8.8
1.5	F	1	5th	76	116	440	10	450	35	12.9
2.6	G	1	ANG	75	133	200	80	280	22	12.7
2.13	H	1	2nd	84	40	228	7	235	82	2.9
2.5		2		92	15	80	7	87	27	3.2
1.6	J	1	ANG	75	53	104	24	128	23	5.6
2.7		2		87	112	272	368	640	31	20.6
2.10	K	1	5th	69	34	175	75	250	30	8.3
1.8		2		96	29	86	80	166	29	5.7
4.3	L	1	TCA	57	135	150	50	200	34	5.9
1.7		2		69	22	58	286	344	26	13.2
1.9	M	1	ANG	81	181	320	400	720	43	16.7
4.2	N	1	5th	64	57	48	29	77	28	2.8
1.4		2		70	53	70	28	98	19	5.2
2.14		3		56	65	230	35	265	19	13.9
2.12	P	1	3rd	53	82	122	70	192	17	11.3
2.11		2		73	70	88	60	148	39	3.8

*Lesson title listed by code number in Table I.

† "2nd," "3rd," and "5th designate Combat Communications Groups; "ANG" = an Air National Guard unit; and "TCA" = Tactical Communications Area headquarters.

Two measures of lesson-production efficiency were recorded: man-hours of effort for each lesson, and calendar days between start and finish. The first is a measure of cost, and the second an indication of the responsiveness of the authoring system to new training demands.

Table II shows the data for the 30 lessons, each characterized by the Author, Preparation Sequence, and Lesson Type variables. To define the Lesson Type, each of the frames was examined for content in terms of "task" and "explanatory" information categories as defined in the authoring procedures. The measure is the ratio of the number of frames that contain task information to the sum of those that contain task information and those that contain explanatory information. Thus, a lesson with purely procedural content (task instructions) is 100 percent on the scale, and one that is purely explanatory (concepts, facts, etc.) is 0 percent. The distribution of lessons by Lesson Type is shown in Fig. 1. The datum at the left, for the lesson Van Orientation, is only 3-percent procedural and therefore is not a valid example of a product of authoring procedures which were designed specifically for task-oriented instruction. Otherwise, the lessons are highly procedural; few of them are as low as 50 percent on the scale. This is consistent with the objective stated in the Lesson Specification in every case, to prepare the novice to perform a maintenance procedure accurately and safely. As a consequence, related facts, concepts, precautions, etc. were limited in scope and were usually associated with single steps and not with whole parts or the entire procedure. (Much of the conceptual material – the system block diagram, equipment layout, and circuits – was covered in prior, formal instruction.)

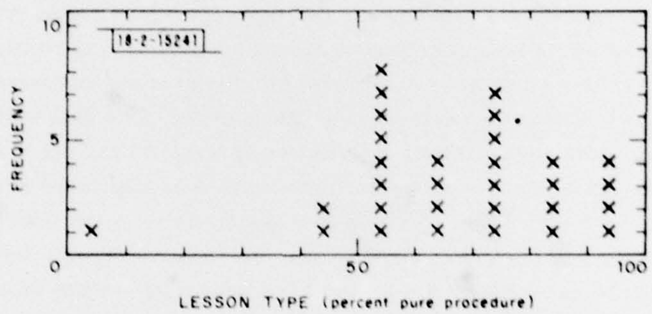

Fig. 1. Frequency distribution of Lesson Type measure for 30 lessons.

The measures of performance are shown for each lesson in Table II. These include the number of frames, the calendar days to complete a lesson, and the man-hours expended by the principal author and the support personnel for each lesson. Time-per-frame, the total man-hours divided by the number of frames, was calculated for each lesson, a measure that is intended to take out the effect of the size of a lesson as a determinant. A summary of these data shows that, on the average, 288 man-hours spread over 75 calendar days is required to produce a lesson.

An analysis of variance was done on the time-per-frame data for the eleven authors who completed at least two lessons. The effects of the Author and the Preparation Sequence variables were tested against the residual (interaction) variance, and neither was statistically significant. Also, a plot of the time-per-frame against the Type measure (percent procedure) revealed no apparent relation. Thus, none of the three major variables considered had a detectable impact on the efficiency of lesson production.

The distribution of the time-per-frame for the 29 task lessons is shown in Fig. 2. The variation is large: it ranges from 3 to 21 hr per frame! The variation is so great that it would seem particularly important to understand the sources of difficulty in preparing the lessons. However, a series of plots and analyses revealed only one consistent effect: 10 of 11 lessons produced as second efforts by an individual had less explanatory information than those produced first. Perhaps other variables not recorded overshadowed those that were, such as the degree to which tasks were fully specified before lesson preparation began. Another possibility is that both the total time and number of frames rose proportionately with increasing difficulty and, therefore, the ratio time-per-frame remained largely unaffected. In any event, little came out of the study to suggest how to better manage or otherwise improve the efficiency of the authoring process.

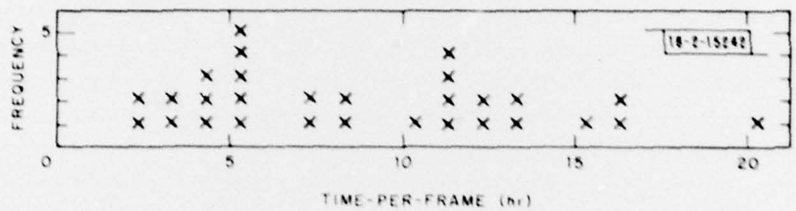

Fig. 2. Frequency distribution of time-per-frame for 29 task lessons.

The overall conclusion is that the feasibility of subject-matter experts producing task lessons has been amply demonstrated under realistic field conditions, although the sources of difficulty in the authoring process did not reveal themselves in the data. Of course, final judgment must be reserved until it is known how effective the lessons are. It is necessary to determine how much training each lesson supports in order to be able to calculate the usual index of the cost of producing a lesson, the number of hours of authoring per hour of instruction delivered. An analysis of the 29 procedural lessons showed that there are about 40 steps in the task per lesson on the average. The tasks – especially the first time they are done – require considerable time to perform. As a result, the lessons support far more hours of instruction than might be expected on the basis of previous applications of computer-based instruction to formal technical schooling.

B. Field Test of the Lessons

A field test of the 30 lessons is being conducted at the 5th CCGp of the AFCS at Robins Air Force Base, Georgia. This is part of a larger study to assess the cost-effectiveness of this new technology as a means of modernizing training within this military organization. The materials prepared using the ARPA Authoring System are delivered on the LTS-5. The performance will be compared with that of a conventionally trained group – one-on-one instruction by expert technicians – at the 3rd CCGp. An independent research company, Scientific Applications, Inc., has been engaged by AFCS to evaluate training at each site. Since the capacity of the computer-based terminal to deliver quality instruction has been established,[2-7] the comparison of pre- and post-test scores for the 10 to 15 trainees of the experimental group at the 5th CCGp will constitute largely a validation of the lessons themselves, and therefore the authoring system. The independent study results will be reported in the summer of 1979 by Scientific Applications, Inc.

Meanwhile, another kind of data, the records made on digital cassette tape on the LTS-5 units during training, constitute a source of lesson validation, summative as well as formative evaluation. Consider two characteristics of the task-oriented instruction provided in this case. First, conditions in the learning situation are very much the same as those encountered in the shop and field. Second, the trainee can not complete the lessons without performing the tasks correctly, because checks at each stage of task performance are an integral part of each task lesson. Therefore, the fact that a lesson has been completed during training is strong evidence that the trainee will be able to perform the task under work conditions, and by definition the training is valid. (This prediction is based on the usual finding in psychometrics that a work sample test is a reliable predictor of work performance.)

Data for 135 hr of training have been obtained. Four trainees, recent electronics graduates of the Keesler School for Applied Aerospace Sciences, have each taken the first 17 lessons. Because the more-complex procedures need rehearsal, several of the lessons were taken twice. The initial results indicate that it takes about 3 hr to complete a task lesson on the first try, and half that time on the second. The average time-per-frame is on the order of 5 min., a reflection of the task-oriented nature of the lessons. Another consequence is that, despite the large amounts of time spent producing a frame, the usual measure of efficiency, the number of hours of authoring required to support 1 hr of training is only about 72 hr per hour, low in comparison to other circumstances.

These initial results suggest feasibility, but do not in themselves prove that task training in this manner is cost-effective in on-the-job environments. In the next section, a cost analysis is applied to the case of the Combat Communications Groups.

C. Cost Analysis

The use of technical aids to work-performance training in the on-the-job environment is a new area of application of automated instruction. The conditions are very different from those in school environments. Thus, an analysis for the Combat Communications Groups is presented here that may generalize to other on-the-job environments. It is based on the actual cost incurred in the project, on preliminary results of the field trial, and on estimates of operational costs for a 5-year period. The project budget is summarized in Table III in terms of one-time and continuing expenditures. These serve as the primary source of data in the cost analysis.

Consider first the cost of delivery of instruction. Delivery units are amortized over a 10-year period. The Air Force currently has five machines and if they are employed over 10 years in 75 percent of single-shift training, the total capacity for training is 75,000 hr. The cost of five units, at an inflated price that reflects the high cost of production in an R&D environment, is shown in Table III as $220,000, or $44,000 per unit. Other expenses include $50,000 for unit maintenance ($1000 per unit per year), and $110,000 for training supervision (10 percent of total training time, 7500 hr, at $15/hr). The total ($380,000), over 75,000 hr of training, implies approximately $5/hr as the cost of instructional delivery.

The other major cost is lesson development. The lessons are amortized over 5 years. Almost all the cost is in labor, 8600 hr for initial versions of the lessons and an additional 50 percent or 4300 hr for lesson maintenance. Much of the graphics arts preparation was done by Air Force personnel and is included as labor; the cost of supplies, travel, etc., was very small in comparison and has been neglected. The total, 12,900 hr, at $15/hr amounts to

TABLE III SUMMARY OF PROJECT COSTS ($1000's)		
Cost of System Development:		
Author Facilities		30
Authoring Procedures		180
Research		130
	Total	340
Cost of Preparation and Delivery:		
Delivery Units		220
Lesson Preparation		190
	Total	410

$190,000. There are 37,500 hr of training capacity available in 5 years, with 5 machines operated 75 percent of a single shift, and therefore the cost of instruction attributable to lesson preparation is about $5/hr.

Based on an exact calculation, the total cost per hour is $10.26. This is 32 percent less than the $15/hr assumed for the cost of an expert who might serve as a trainer or as an author. An investigation has been conducted of the sensitivity of the cost of instruction to the major parameters that might change due to circumstance. Consider three cases. (1) If the cost of production copies of LTS-5's is one-third that of the Laboratory-built units, the effect on cost per hour is a decline of 20 percent. (2) Doubling the training capacity from 313 to 626 over 5 years would reduce the cost per hour by 25 percent, because lesson materials make up half the cost and they would be amortized over twice the population. (3) Were the lessons to support 80 instead of 120 hr of training, the cost would rise to about $13/hr. The conclusion drawn from these investigations is that no one variable dominates, and that there are savings in the cost of instruction over a wide range of conditions.

Another potential benefit overshadows the improvement in the efficiency of training that machine-aided instruction permits. It relates to the timeliness of instruction. A matter of paramount interest to the unit commander is the months on duty the average trainee spends before being fully qualified to maintain equipment. Currently, trainees in the Combat Communications Groups remain 6 months or more in a training status before they become fully qualified. On the basis of the initial results with LTS-5 training – the best data available – it is estimated that the total requirement is 160 hr of instruction. Spread over 6 months, this amounts to 6 hr on duty for each hour of training. The rate for LTS-5 instruction has been about 3 hr of training per man per day or 2.7 hr on duty per hour of training. Given that 120 of the 160 training hours can be met on the LTS units, the total saving of time to reach qualification is 400 hr, 40-percent less than usual. This benefit derives from the fact that live trainers are often not available due to the press of other duties, but LTS units are.

D. Other Findings

In many respects the effort reported here is a unique one, the application of technology to hands-on training in the work environment. The opportunity to compare conventional labor-intensive and machine-based methods made some issues clearer, and these represent advances in understanding the nature of training in this neglected area. The broader implications are reviewed here.

It is feasible for experts in the maintenance and the operation of technically sophisticated systems to prepare lesson materials that convey their expertise to novice technicians. Capturing the expertise is accomplished by adherence to a fairly straightforward set of authoring procedures; it does not depend on assistance from educational specialists or professional media experts. Preliminary results in this regard confirm those from other applications,[2,5,6] namely that sophistication of lesson design is not essential when training is delivered by a machine that uses a computer to assure that learning occurs. In the preparation of task-oriented instruction, the sequence of steps in the work procedure provides a basis for the author to organize the lesson and to distinguish need-to-know from nice-to-know explanatory material.

The cost of lesson development for each hour of training is affected greatly by the size of the population over which the investment is amortized. Costs of production can be controlled by:

- Avoiding unstandardized, untested procedures as the basis for a task lesson
- Using an expert in the subject matter to author
- Simplifying the frame design with respect to graphic arts audio recording and computer programming requirements
- Using procedure, not training, to manage the authoring process
- Providing facilities to check out lesson program logic
- Making certain lessons are tried on several trainees before final commitment.

The general impression is that planning and management are far-more-important factors affecting the efficiency of lesson production than educational considerations, a good match to the manpower resources available in on-the-job environments.

In the past, emphasis has been placed on two methods of improving task performance, provision of more detailed and precise instructions in job aids (manuals, etc.), and improvement of the problem solving skills of the technician. As to the first method, for complex systems there are so many contingencies that the technician faces in the course of performing a standard maintenance procedure that it is not feasible to anticipate and provide for them all; performance depends on comprehension of the nature of the equipment and the task. As to improving reasoning skills, the journeyman technician only occasionally is required to find faults and solve other problems by inferential methods. Training is directed mainly to learning the equipment design, operational doctrine, safety matters, and work steps, not as separate skills but as they apply to execution of procedures to achieve specific work goals. No amount of prior component skills training nor improved documentation can substitute for this kind of one-on-one instruction.

In the area of task training for complex equipment and systems, it is quite clear that the usual "ISD" (Instructional Systems Development) procedures have limited application. The principles on which the procedures rest, such as those given in the Interservice Manual,[13] are sound but the methods are not appropriate. There is an unqualified recommendation to analyze the work tasks into component skills and to develop separate training for each area. This approach by itself is inadequate as preparation to perform complex tasks, when the criterion objective is to have the trainee demonstrate proficiency in the task itself.

E. Summary

The resources required to prepare and conduct technology-based performance training in on-the-job environments are:

- The ARPA Authoring and Management Procedures
- Subject-matter experts to prepare materials
- A small computer system to record audio and logic and to analyze data
- Stand-alone training units
- Operational equipment to train on.

The preliminary results of the initial operational test and evaluation of applying these resources in the Combat Communications Groups indicate that at least 20,000 hr of highly qualified technician time and 125,000 hr of recently qualified technician time can be saved over the next 5 years. In addition to the investment of available resources, outside procurement funds required to realize this benefit have been on the order of 10 percent of the value of the projected labor savings.

This means for improving the efficiency of task training can be replicated, and is believed to have widespread application in the Armed Forces. Quantity production of LTS-5 units will reduce the cash expenditure required to less than 5 percent of the value returned.

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A review is presented of the project to develop and field test the ARPA Authoring System for use by subject-matter experts in the preparation of task training in on-the-job environments. Materials were prepared according to the ARPA Authoring System procedures, and both preparation and delivery were on the facilities of the Lincoln Terminal System. An analysis of the lesson production rates for 30 lessons prepared by Air Force personnel revealed no systematic effects related to individual author, authoring experience, or lesson type. Preliminary results from a field test of the materials indicate that the lessons are sound. Large savings were found in the time trainees require to reach job qualification and in the amount of labor that subject-matter experts must dedicate to training duties.

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